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MACHINING PERFORMANCE ENHANCEMENT OF BRASS C360 ALLOY USING TAGUCHI BASED GREY RELATIONAL ANALYSIS METHOD

HIMANSHU BORADE[1], Dr. AMIT TELANG[2] & Dr. SANJAY SONI[3]

[1]*Research Scholar, Department of Mechanical Engineering, M. A. N. I. T, Bhopal, Madhya Pradesh, India*

[2]*Assistant Professor, Department of Mechanical Engineering, M. A. N. I. T, Bhopal, Madhya Pradesh, India*

[3]*Associate Professor, Department of Mechanical Engineering, M. A. N. I. T, Bhopal, Madhya Pradesh, India*

ABSTRACT

The present work is based on the optimisation of the process parameters during milling of brass C360 with using Taguchi method with grey relational analysis. Nine experimental trials are conducted using Taguchi orthogonal Array. Tool speed, feed rate & cutting depth are optimized by taking different performance characteristics as a response such as surface roughness (R_a) & material removal rate (MRR). Analysis of variance (ANOVA) has been applied to find out the contribution of control parameters on the response. The confirmation experiment finally validated optimal parameter values obtained during the analysis.

KEYWORDS: Taguchi Method, GRA, ANOVA & MRR

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Original Article

Abbreviations

CNC	Computer numeric control
ANOVA	Analysis of variance
GRA	Grey Relational Analysis
SR	Surface Roughness (μ m)
MRR	Material removal rate (mm^3/min)
TS	Tool speed
FR	Feed rate
CD	Cutting depth

INTRODUCTION

Brass and its alloys are commonly used in industries because of inherent properties such as greater malleability, strong machinability, high castability[1]. The brass's properties can be changed by varying the proportions of copper and zinc, allowing for hard and soft brasses. C360 Machining Brass is a soft ductile metal which is very easy to machine. It is used both in general applications of screw machines and in high volume manufacturing. The milling process is the metal cutting process most widely used in the manufacturing sector. The main objective of this approach is to produce high quality parts with high surface quality within a reasonable period of time. The manufacturing sector relies heavily on machining with CNC milling machines due to some of its important

characteristics such as high production & scalability, versatility, low maintenance, accurate machinability etc. MRR also plays a vital role to increase the productivity in industries. MRR can be increased by choosing the right combination of parameters such as FR, tool speed and cutting depth [3]. TS, FR and cutting depth are the main controlling parameters. These controlling parameters directly influence SR of the machined component. Previous researchers have reported effect of process parameters in end milling of different materials. Sakthivelu et al.[4] used Taguchi method to explored the machinability of aluminium alloy and used machining response as variable in the selection of MRR and SR(Ra). They found that rate of feed was the most important factor with respect to SR, and cutting depth was the most predominant factor with respect to MRR. During the milling process, Subramanian et al. [5] analysed the SR of aluminium alloy and stated that as the rate of feed increases SR also increases, while SR decreases with increased tool speed. Rajeswari et al. [6] investigated the control parameters on SR and tool wear rate, when Al356-SiC metal matrix composite is used as a material in end milling. They concluded that TS had the most significant parameter with respect to SR and tool wear rate followed by angle of helix and angle of rake. Ibrahem Maher et al. [7] optimized control parameters tool speed, FR and cutting depth during machining of brass alloy and concluded that SR decreases with increase in tool speed. Using Taguchi method, Anis Nair et al. [8] optimized milling parameters of brass alloy on SR. They concluded that the tool speed has the most significant effect on SR. Kadirgama et al. [9] predict the effect of TS, axial depth, and radial depth on SR of aluminium alloy in the milling process. They found that FR is the most important parameter compared to other control parameters. Reddy et al. [10] used the Taguchi method to determine the optimum process parameters for hardened steel hard-machining. They found that the TS is the parameter most affecting the life of the tool and the roughness of its surface. Akash sharma et al. [11] was investigated that the SR of Aluminium Alloy AA6062 is mainly affected by rate of feed which is followed by tool speed and cutting depth. An Industry-based work has been carried out by Navneet et al. [12] to provide an in-depth analysis of the milling parameters of cast iron on CNC milling machine, taking into account three surface parameters such as concavity, straightness and roughness (Rz) with CBN inserts. By applying signal to noise ratio analysis, they found that Tool speed has the major and feed has the minor contribution among the control variables.

Most of the work was done in materials like aluminium alloys, composite materials, cast iron etc. therefore, brass C360 is used as a material for research work due to some of its outstanding high-tool speed machining, and exceptional thread rolling and knurling features. In this work, an attempt was made to conduct experimental investigations on C360 brass content throughout end milling in order to examine the impact of process conditions on surface finishing and MRR.

2. EXPERIMENTAL DETAILS

2.1 Material

Machining brass C360 is the material used in the experiment which is produced from a combination of copper and zinc. It possesses a unique property of maximum machinability among all brass alloys. The chemical composition and properties are shown in Table 1 and Table 2.

2.2 Specimen Details

In the experimentation, the specimen are having the dimensions 250 mm x 62 mm x 16 mm. The figure 1(a) shows the specimen before machining process while figure 1(b) shows the picture after machining process.

Figure 1 (a): Specimen before Machining

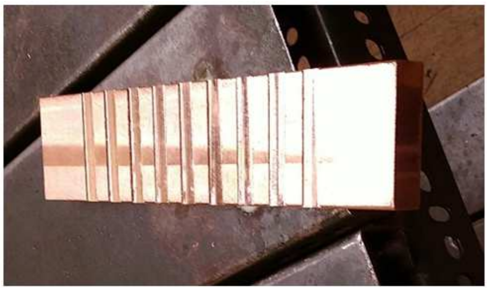

Figure 1 (b): Specimen after Machining

2.3 Machining Process

The machine used in experimental purpose are CNC Milling Machine "Deckel Maho DMC 70v Hi Dyn ". The DMC 70V is suitable for the production of unique pieces in tool design / mould construction and in series production of complex parts Precision, finish quality, durability and high speed cutting are special characteristic of this type of machine. The experimental setup is shown in Figure 2(a) & Figure 2(b).

Figure 2(a)

Figure 2(b)

2.4 Cutting Tool

The cutting tool used is a 10 mm diameter end mill cutter. The material of cutting tool are high speed steel. In all the experiments, the uniform machining length, width, and depth were preserved.

2.5Process Parameters

In present work, tool speed (rpm), FR (mm/min) and cutting depth (mm) was considered as control parameter in order to minimize the SR and maximize the MRR. Each parameter was assigned three level values shown in Table 3. The experimentation has been done according to Taguchi's L9 orthogonal array which is shown in Table 4.

Table 1:Chemical Composition of Specimen

Elements	Copper	Zinc	Iron	Lead
Weight (%)	60-65	35.5	0.35	2.5-3.7

Table 2: Properties of Specimen

Elements	Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation	Rockwell Hardness
Weight (%)	58,000	45,000	25%	B78

Table 3: Parameter level value

Level	Tool Speed (rpm)	FR (mm/min)	Cutting depth (mm)
1	2500	200	0.4
2	3500	400	0.6
3	4500	600	0.8

Table 4: Experiment Table

Exp. No	Control Factors			Responses	
	Tool Speed (rpm)	FR (mm/min)	Cutting Depth (mm)	Ra (µm)	MRR (mm^3/min)
1	2500	200	0.4	1.492	800
2	2500	400	0.6	1.38	2400
3	2500	600	0.8	1.46	4800
4	3500	200	0.6	1.28	1200
5	3500	400	0.8	1.32	3200
6	3500	600	0.4	1.39	2400
7	4500	200	0.8	1.18	1600
8	4500	400	0.4	1.295	1600
9	4500	600	0.6	1.242	3600

2.6 Surface Roughness Measurement

The surface roughness was measured by using surface roughness tester (Mitutoya Talysurf SJ-210).

3. EXPERIMENTAL DESIGN & OPTIMIZATION

Three control parameters for each control factor are included in the analysis, with three levels. The orthogonal Taguchi L9 array is used for experimental study. Therefore, the study requires 9 trails, and the format for the experiment is shown in Table 4.

3.1 Taguchi Technique

Taguchi has derived a method of conducting minimum no of experiments which are based on orthogonal arrays. Those standard arrays provide a way to conduct the minimum number of experiments that could provide full knowledge of all the factors affecting the performance parameter[5].

The overview statistic (η) in Taguchi system is called signal-to-noise (S/N) ratio. The value of (η) is an important index for evaluating the impact of parameters of processing on properties. The summary statistic (η) is defined as the following formula:

$$\eta = 10 \log(\text{S/N ratio}) = 10 \log 1/\sigma^2 = -10 \log\sigma^2 \quad (1)$$

For, Smaller-the-better (SB) $\sigma^2 = 1/n\ (z_1^2 + z_2^2 + z_3^2 + \ldots\ldots\ldots + z_n^2)$ (2)

For, Larger-the-better (LB) $\sigma^2 = 1/n\ (1/z_1^2 + 1/z_2^2 + 1/z_3^2 + \ldots\ldots\ldots 1/z_n^2)$ (3)

Where (η) denotes the calculated value of S/N ratio (unit: dB).

3.2 Grey Relational Analysis

GRA involves three main steps for analysis. In the first step normalization has been done so that all the values comes between 0 to 1. Since the goal is to minimize SR, the equation ' smaller is better ' is chosen and can be represented as

$x_i(\mathrm{k}) = \frac{max\ z_i(k) - z_i(k)}{max\ z_i(k) - min\ z_i(k)}$ (4)

For MRR, larger-the-better criteion can be expressed as:

$x_i\ (\mathrm{k}) = \frac{z_i(k) - min\ z_i(k)}{max\ z_i(k) - min\ z_i(k)}$ (5)

The Grey Relational Coefficient is obtained by:

$\xi_i = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}}$

$\xi_i = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}}$ (6)

$\Delta_{0i}(k) = \|x_o(k) - x_i(k)\|$ (7)

where $\Delta_{0i}(k) = \|x_o(k) - x_i(k)\|$

Δ_{min} and Δ_{max} are respectively the minimum and maximum values of the absolute differences (Δ_{oi}) of all comparing sequences.

After averaging the Grey relational coefficients, the Grey relational grade γ_i can be calculated as follows:

$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi i(\mathrm{k})$ (8)

4. RESULTS & DISCUSSIONS

4.1 Effect of Parameters on Surface Roughness

4.1.1 S/N Ratio Analysis

Through selecting the levels at which the S/N ratio is the highest, Taguchi method gives the optimum level combination.

Figure 3 explains the main effect on surface roughness of process parameters i.e. tool speed, FR and cutting depth. The slope of the plot gives the information about nature of parameters. SR decreases with high spindle speed, low FR and high cutting depth.

The mean S/N ratio for SR is given in Table 5. Tool speed and cut depth are the most relevant parameters from the Table for SR followed by FR. For minimal SR, the ideal combination of parameters is A3B1C3.

Table 5: S/N Table for SR

Level	Speed (A)	FR (B)	DOC (C)
1	-2.868	-2.199	-2.669
2	-2.369	-2.410	-2.480
3	-1.955	-2.583	-2.044
Delta	0.912	0.383	0.626
Rank	1	3	2

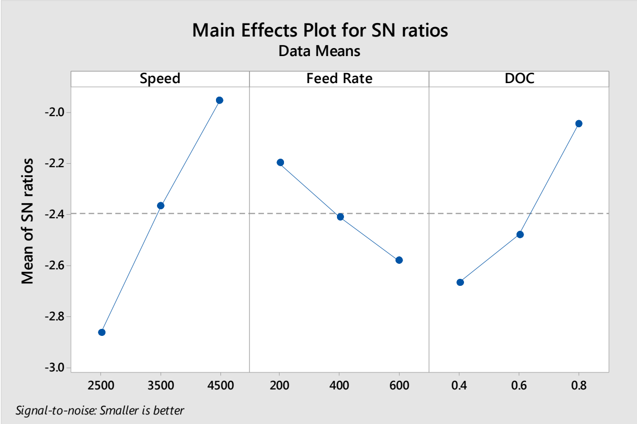

Figure 3: S/N plot of SR.

4.1.2 ANOVA Analysis

ANOVA is used to research the significant effect of the machining parameters on responses. The table on ANOVA contains the degrees of freedom, the sum of squares, the mean square and the contribution percentage of parameters.

In terms of experimental significance, higher percentage contribution arc parameters rank higher and also have significant effects in controlling overall response.

ANOVA has been applied in the current work to analyze the percentage contribution of the control parameters, namely tool speed, FR and cut depth, which greatly affects surface SR and MRR ANOVA tests of SR are shown in Table 6.

It is evident from the table that the tool speed has a higher percentage of contribution to controlling the brass C360 alloy SR (P = 57.46 percent), followed by the cutting depth (P = 27.41 percent) and FR (P = 8.99 percent).

Table 6 ANOVA Table for SR

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Speed	2	0.028694	0.014347	9.38	0.096	57.46
FR	2	0.004491	0.002245	1.47	0.405	8.99
Cutting depth	2	0.013691	0.006980	4.56	0.180	27.41
Error	2	0.003059	0.001529			6.12
Total	**8**	**0.050204**				

4.2 Effect of Parameters on MRR

4.2.1 S/N Ratio Analysis

Figure 4 highlights the main effect plot of process parameters for MRR. It is observed that high level of FR and cutting depth results in higher MRR. Tool speed has not displayed significant effect on MRR. The mean S/N ratio for MRR is given in Table 7. From the Table, FR and cutting depth are most important parameters for MRR and tool speed has no effect. The maximum MRR is obtained for the optimal combination of parameters (A3B1C3).

Table 7: S/N Table for MRR

Level	Speed (A)	Feed Rate (B)	DOC (C)
1	66.43	61.24	63.25
2	66.43	67.26	66.77
3	66.43	70.79	69.27
Delta	0	9.54	6.02
Rank	3	1	2

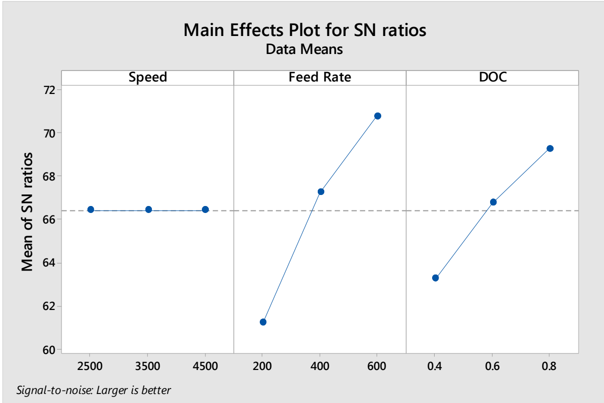

Figure 4: S/N plot of MRR.

4.2.2 ANOVA Analysis

Results of ANOVA are shown in Table 8 and % contribution of control parameters on MRR. It is also shown from the table that FR is most influencing parameters with contribution of 65.85% and followed by cutting depth 29.27% and speed 2.44%. Increase in FR and cutting depth increases the MRR.

Table 8: ANOVA Table for MRR

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Tool Speed	2	32000	160000	1	0.5	2.44
FR	2	864000	4320000	27	0.036	65.85
Cutting depth	2	384000	1920000	12	0.077	29.27
Error	2	32000	160000			2.44
Total	**8**	**1312000**				

4.3 Grey Relational Analysis

Table 9: Normalized value & Deviation Sequence for Response Parameter

Exp. No	Normalized Value		Deviation Sequence	
	SR	MRR	SR	MRR
1	0	0	1	1
2	0.045	0.4	0.954733	0.6
3	0.341	1	0.658436	0
4	0.617	0.1	0.382716	0.9
5	0.584	0.6	0.415638	0.4
6	0.135	0.4	0.864198	0.6
7	1	0.2	0	0.8
8	0.625	0.2	0.374486	0.8
9	0.465	0.7	0.534979	0.3

Table 10: Grey Relational Co-efficient and Grades

Exp. No	Grey Relational Co-efficient		Grey Relational Grade (GRG)	Rank
	SR	MRR		
1	0.333333	0.333333	0.333333	**9**
2	0.343706	0.454545	0.399126	**8**
3	0.431616	1	0.715808	**1**
4	0.566434	0.357143	0.461788	**6**
5	0.546067	0.555556	0.550811	**4**
6	0.366516	0.454545	0.410531	**7**
7	1	0.384615	0.692308	**2**
8	0.571765	0.384615	0.47819	**5**
9	0.483101	0.625	0.554051	**3**

According to GRA, experiment No 3 gives the optimum results of minimum SR of 1.46 μm & maximum MRR of 4800 mm^3/min. therefore the combination of tool speed 2500 rpm, FR 600 mm/min and cutting depth 0.8 mm gives the best results.

5. CONFIRMATION TEST

Experiment validation was performed at optimum parameter i.e. tool speed 2500 rpm, FR 600 mm/min and cutting depth 0.8 mm. The average SR was measured are 1.488µm. The average absolute error was found to be 1.9% which is within acceptable limit.

6. CONCLUSIONS

The following conclusions were drawn:

- By Taguchi's single objective function the result shows that an increase in speed, cutting depth level and decrease in FR level results in lower SR.
- Higher level of FR and cutting depth results in increase in MRR.
- Results of ANOVA show that speed and cutting depth are the most influential parameters for SR with a percentage contribution of 57.15 and 27.27 respectively.
- ANOVA results also shows that that cutting depth and FR are the most important parameters for MRR with a percentage contribution of 65.85 and 27.29 respectively.
- The optimum parameters obtained by using grey relational analysis for minimum SR: tool speed 4500 rpm, FR 200 mm/min and cutting depth 0.8 mm.
- The optimum parameters achieved by using grey relational analysis for maximum MRR: tool speed 2500 rpm, FR 600 mm/min and cutting depth 0.8 mm.
- Confirmation test is performed with optimum parameter. The difference between experimental outcome and expected result is well within the calculated interval confidence.

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AUTHORS PROFILE

Mr. Himanshu Borade is working in Medicaps University, Indore in Mechanical Engineering Department since last 10 years. He has done M. Tech in Design and Thermal Engineering from Institute of Engineering & Technology (IET, DAVV), Indore. Currently he pursuing PhD from MANIT, Bhopal in Production Engineering. He has successfully supervised 15 M. Tech scholars.

Dr. Amit Telang is an Assistant Professor in Department of Mechanical Engineering MANIT, Bhopal, India since last 15 years and having an experience of over 26 years of teaching. He has done PhD in the field of Composite material from MANIT, Bhopal in 2013. He has published over 40 papers in international and national journals and conferences. He also guided over 35 PG dissertation, 06 UG dissertation, and 01 PhD scholar. He has the member of some reputed professional bodies such as Institution of Engineers India (IEI), Indian Society for Technical Education etc.

Dr. Sanjay Soni is an Associate Professor in Department of Mechanical Engineering MANIT, Bhopal, India since last 25 years. He has done PhD in the field of Composite material and having more than 25 years of experience. He has published more than 30 International journals and has successfully supervised 54 M Tech scholars and 2 Ph.D. scholars and 4 are ongoing.